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(54) ALL CARBON COMPOSITE DISC STRUCTURES

(71) We, THE BENDIX CORPORATION, a corporation organised under the laws of the State of Delaware, United States of America, of Bendix Center, Southfield, Michigan 48075, United States of America, formerly of Springfield, Michigan 48075, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to annular discs having improved strength and resistance in the peripheral regions thereof and which are suitable for use as components of disc brake assemblies.

Due to the increased size and landing speeds of modern aircraft, much emphasis is being placed upon the development of superior brakes to reduce the motion of the aircraft. Aircraft ordinarily employ disc brakes which function much like those of a pedal actuated bicycle brake consisting of a stack of alternating rotors and stators. The rotors and stators having splined peripheral regions are coupled to the wheel and axle respectively. When the members are pressed together, the motion of the aircraft is reduced due to the frictional force of the friction element attached or positioned between and against the rotor and stators. Simultaneously, a large amount of energy is released as heat, and a large stress is created in the splined areas of the rotors and stators. The splined areas are ordinarily located along the outer periphery of the rotor and the inner periphery of the stator.

Present developments are focusing upon various materials which can withstand both the mechanical stress and the deleterious effects caused by the generation of heat. A material which has shown considerable promise is an all-carbon composite. Recent evaluation, however, of all-carbon composites based upon laminated carbon or graphite cloth have shown that the interlaminar strength of the disc has not been entirely satisfactory, particularly in the splined regions of the discs. Besides failure through breakage, such discs also have a tendency to fail through delamination in the splined region.

A further deficiency of carbon composites is their inability to resist oxidation at high operating temperatures such as may be encountered when operated as aircraft brake discs. Temperatures as high as 1400°F. are often reached when a modern aircraft lands and is decelerated. The portions of the aircraft brake discs which are exposed to the surrounding atmosphere often experience oxidative degradation. Generally, the exposed portions of a disc are the splined regions since the frictional regions are in intimate contact with frictional regions of other brake discs. Oxidative degradation at these high operating temperatures tends to weaken the splines which must withstand the large stresses generated in braking the aircraft.

It is therefore a primary object of the present invention to provide an improved composite structure having increased resistance to delamination in the peripheral regions thereof and which may be used under conditions which subject the peripheral regions to high stresses.

In its broadest aspect the invention provides a substantially all-carbon composite annular brake disc, said disc being formed throughout by carbon fibres in a carbonaceous matrix and having protrusions or indentations along one of its peripheries, wherein the region of the disc adjacent said one periphery comprises a band of continuous carbon fibres which are located in said carbonaceous matrix so that they

follow substantially the contour of said one periphery of the disc.

In one preferred embodiment of the invention the disc has, at least in the peripheral region, a surface coating of a material having a melting point greater than 1400°F or which is a viscous film-forming liquid at 1400°F the said material being substantially inert in the presence of oxygen and substantially impermeable to the passage of oxygen therethrough.

In the embodiment that is particularly adaptable for use in a disc brake assembly, the annular disc has splines along said periphery thereof, and the surface coating covers at least the splines.

The matrix is the constituent of the composite which surrounds the other composite elements, such as fiber reinforcement components, and acts or has acted as a cementing medium. The material utilized as the matrix may be of any carbonaceous material or a material which yields a carbonaceous residue upon high temperature pyrolysis. An example of such a matrix material is a phenolic resin containing dispersed particulate carbon or graphite.

The particular arrangement of the fibers in the peripheral regions subject to the high stresses gives a structure having a greatly improved stress capacity along the plane of the planar structure and also increased resistance to delamination. The expression "ordered direction" is intended to cover the general orientation of the fibers. Although the fibers may cross one another, the general and predominant direction in which the fiber paths extend is along the contour of the periphery of the planar structure. The term periphery may be the outer or the inner perimeter of the annular disc.

The invention also provides a disc brake assembly comprising a stator disc fixed in relation to an axle and a rotor disc fixed in relation to a wheel mounted on the axle, in which each disc is an annular disc as defined above and the discs are adapted, by relative axial movement, to engage over frictional areas of their adjacent major faces and to disengage, and in which the surface coating on each disc covers substantially all surfaces of the disc except the frictional area.

In a modified disc brake assembly, a frictional element or frictional material is located between the stator disc and the rotor disc and the surface coating on each disc covers substantially all surfaces of the disc except the areas in contact with or which engage with the frictional element or material.

The coating material comprises a preferred aspect of the invention. It is necessary that the protective coating be essentially impermeable to the passage of oxygen therethrough. The impermeability of the coating depends upon a number of factors such as the nature of the coating, thickness, and porosity. The nature of the material includes physical characteristics such as diffusability and is controlled through the selection of materials to be utilized. On the other hand, thickness and porosity to some degree are controlled by the manner in which the material is applied to the element.

Additionally, the coating material should be essentially inert in the presence of the atmosphere under operating conditions. Because a substantial number of materials undergo minor reactions in environments similar to that experienced by the brake discs, it is to be understood that essentially inert materials is meant to include those materials which when applied as a coating will accomplish the result desired, i.e., retardation of oxidative degradation of the carbon rotor or stator disc, for a commercially acceptable time, even though some reaction may take place.

Still another required characteristic for the coating material is that it must be able to perform the desired function at the high temperature levels which may be reached. Thus, the material utilized preferably should have a high melt point, i.e., greater than about 1400°F. or alternatively, have a viscosity of sufficient magnitude in the molten phase to maintain the material as a coating.

The thickness of a coating depends primarily on the physical characteristics of the material or materials utilized. It has been found, however, that a thickness of 2—15 mils is preferable.

Another desirable characteristic for the materials employed as protective coatings is ductility. The frictional contact between adjacent discs due to actuation of the brake assembly causes the splined regions to abruptly move against the mating keys of the wheel axle and stationary torque tube. A brittle coating on the splined regions would readily chip and break under the abrupt contact. Thus, it is necessary that the material used for the protective coatings possess sufficient ductility to withstand repeated brake operation.

Although the geometry of the disc prevents significant movement of the coating on the disc, it is preferable, however, that the coating be applied so as to fit closely to the disc. A differential in the coefficients of expansion may cause spaces to occur between the coating and the disc at increased temperatures. The atmosphere readily enters the spaces causing the undesired oxidation of the carbon composite. It is evident in view of the above that it is desirable to match the coefficients of expansion. The coefficient of expansion of the carbon composite depends upon a number of factors such as, for ex-

ample, fiber orientation, fiber concentration, and degree of graphitization. Generally, the range of coefficients of expansions thereof is from about 1 to 5×10^{-6} inches/inch/°C. There are a number of suitable materials falling within or near this range which may be employed as a coating. Among such materials are chromium and metal oxides like alumina.

It is not necessary to limit the coating to one material, however. For example, a plurality of different materials may be utilized in the fabrication of a graded coating comprising a plurality of sub-coatings. A graded coating is particularly attractive when it is desirable to closely match the coefficients of expansion of the coating and carbon composite, but the available materials with matching expansion coefficients deteriorate beyond acceptable limits due to oxidation. The initial or inner sub-coating according to this technique has nearly the same coefficient of expansion as that of the carbon composite. The sub-coatings progressing outwardly from the composite have expansion coefficients larger than but closely matching the expansion coefficients of the adjacent inner sub-coatings. The outer sub-coating is necessarily substantially non-reactive to oxygen at the elevated temperatures reached during brake operation. Thus, the gaps or spaces normally appearing when using a single coating of material having a significantly larger expansion coefficient than that of the carbon composite are essentially eliminated. Concurrently, the inner sub-coatings and the carbon composite are protected against oxidation.

An example of a material which has a matching expansion coefficient but which is readily attacked by oxygen is molybdenum. Nickel on the other hand resists oxidation, but has a coefficient of expansion of about 15×10^{-6} in/in/°C., significantly larger than the carbon composite. By using a plurality of sub-coatings therebetween such as, for example, alloys of nickel and molybdenum, a graded coating may be fabricated with the desirable characteristics as described above.

It should now be appreciated that any material or materials which have the characteristics as stated above are suitable for use as a coating over the surface of the carbon composite structure. One representative group of materials which have been found to be suitable are the metals which includes the metal elements, alloys thereof, and intermetallic compounds. Examples of suitable metals are copper, gold, silver, and nickel.

Another group of suitable materials are the ceramics such as, for example, alumina, beryllia, silica, zirconia, boron carbide, and molybdenum disilicide. Ceramic materials are hereindefined as any class of inorganic, non-metallic products which typically, but not exclusively, include metallic oxides, borides, carbides, nitrides, and mixtures or compounds of such materials. Certain metalloids such as, for example, boron and silicon are also suitable as coating material.

There are a variety of ways that coatings may be applied such as electroplating, sputtering, and flame spraying. Perhaps the most preferable is a technique known as arc-plasma spraying which may be employed to deposit a variety of different materials. Because the arc-plasma generator utilizes an inert or nonoxidizing gas (usually argon, helium, or nitrogen) to form the plasma stream, a wide range of compositions may be injected into the plasma jet for controlled melting and deposition as a coating on the unmasked regions, e.g., splined regions, of the carbon composite disc.

Still another technique commonly called "glazing" may be utilized. For example, silica or silicon in an organic binder solution may be applied to the splined regions of the disc. By subjecting the disc to temperatures in excess of the melting point of silica in an inert atmosphere, the silica melts while the organic binder is burned away. The coating or glaze of silica then constitutes the protective layer over the spined regions of the disc.

Various embodiments of the invention will now be described with reference to the accompanying drawings in which:

Figure 1 is a simplified vertical view, partly in section, of a typical aircraft brake system.

Figure 2 is a diagrammatic top plan view of the body of an all-carbon composite rotor member.

Figure 3 is a perspective view of the rotor member body of Figure 2.

Figure 4 is a diagrammatic plan view of the body of a stator member.

Figure 5 is a perspective view of a rotor member showing the protective coating.

Referring to Figure 1 which illustrates a simplified aircraft brake assembly, there is shown a horizontal axle 10 to which a wheel 11 is appropriately journaled through roller bearings 12 (only one of which is shown). The brake assembly portion comprises (I) a plurality of annular disc-shaped rotor members 13 which are keyed or splined to wheel 11 via member 14 and (II) a plurality of annular disc-shaped stator members 15 which are keyed or splined to the stationary axle 10 via member 19.

Each of the rotor members 13 and stator members 15 is provided with rotor frictional elements 17 and stator frictional elements 18. These are respectively positioned against the opposite faces of rotors 13 and stators 15 which in turn are adapted to be compressed against back plate 19 by means of a hydrau-

lically actuated pressure mechanism or other appropriate means (not shown).

Figure 2 is a plan view illustration of the body of a rotor member 20 which may be utilized in the apparatus illustrated in Figure 1. The rotor 20 is an annular disc having six splines 21 along the outer circumference or periphery thereof. Splines 21 function to couple the rotor 20 to wheel 11 by means of axle 10 (as seen in Figure 1).

When the brake assembly of which rotor 20 is a part is actuated, rotor 20 is pressed tightly against an adjacent stator friction element to provide the frictional force needed to reduce the rotational speed of the wheel and, therefore, the aircraft. The frictional surface area is inside the region encompassed by the root diameter of splines 21. Thus, because the driving force (see reference numeral 22) is acting in a direction tangential to rotor 20 and the frictional force (reference numeral 23) is acting in the opposite direction, large stresses are developed in the region of splines 21. It is therefore imperative that the rotor 20 comprise materials which are able to withstand the stresses which develop in the disc.

The body of the rotor 20 is comprised of an essentially all-carbon composite which includes continuous carbon or graphite fibers (carbon being employed hereinafter as generic to both) in a carbonaceous matrix. To better illustrate the fibrous nature of the body, the fibers therein are greatly exaggerated via heavy lines. The carbon fibers in the regions adjacent splines 21 have an ordered direction which follows the contour of the splined periphery. The fiber continuity and designated ordered direction provide increased strength when compared to similar members made with laminar or all-staple fiber constructed composites. A structure in which the continuous fiber path crosses is preferred, since this ensures that delamination does not occur under stress as may happen in laminated structures.

To better illustrate the ordered direction of the continuous carbon fibers, rotor 20 is shown in perspective in Figure 3. The carbon fiber has been drawn only in regions near the splined periphery. It is evident from Figure 3 that the carbon fiber essentially follows the contour of rotor 20 and also crosses over at many positions.

Figure 4 is an illustration of the body of a stator member 30 which also may be utilized in the brake assembly of Figure 1. As seen in Fig. 4 member 30 is an annular disc having six splines 31 located on the inner periphery thereof. It should be understood that the number of splines is purely a matter of choice. The construction of member 30 is in accordance with another embodiment of the present invention wherein the continuous fibers are utilized only in the region 32 adjacent splines 31. The remaining regions removed from the splines 31 are comprised of other fiber configurations such as, for example, a randomly oriented short carbon fiber staple composite. As before, the continuous fibers sweep about splines 31 in an ordered direction which essentially follows the contour of the splined inner periphery thereby strengthening these regions against stresses.

As stated above, the stators and rotors alone may establish the necessary friction for causing the aircraft to decelerate, or frictional elements may be inserted therebetween. Alternatively, a frictional surface may be applied to both elements in the "friction regions" which are inside the splined region in the case of the rotors and outside the splined region in the case of stators. For example, the region designated by reference numeral 33 in Figure 4 may be recessed and then filled with appropriate frictional material which has a different frictional behavior (i.e., different coefficient of friction) from the carbon composite.

Figure 5 illustrates in perspective an all-carbon composite rotor disc 40 (similar to that illustrated in Figure 2) which has a thin coating 41 of oxidation retarding material applied thereto within the splined regions. Coating 41 functions to retard oxidative degradation of the carbon composite. It should be noted that all surfaces within the splined regions are covered with coating 41 including the faces inside slots 42. It is preferable, however, that the surface areas (illustrated by numeral 43) which frictionally contact the adjacent surface areas be free of coating 41 so as to ensure that the desired frictional characteristics remain unaltered.

To illustrate the improvement in resistance to oxidation achieved by applying a surface coating to a carbon composite, reference is now made to the following Examples in which an uncoated and coated segments of a composite brake disc were subjected to high temperatures.

EXAMPLE I

A segment of a composite brake disc of the type previously described without a coating was accurately weighed and placed in an electrically heated furnace maintained at a temperature of 1600°F. The residence time in the furnace was one hour. Subsequent to subjecting the brake disc segment to the furnace atmosphere, it was removed and permitted to cool to room temperature whereupon the brake disc segment was again accurately weighed for determination of its weight loss. The percent loss in weight was determined to be 18.1 percent. This example demonstrates the degree of weight loss to which the carbon composite brake discs are subjected during use due to oxidation.

EXAMPLE II

An additional segment taken from the brake disc employed in Example I and having substantially the same dimensions was provided with a metal coating by the electrodeposition of nickel on the carbon surface in the absence of a copper strike.

Prior to the application of the nickel coating the brake disc segment was cleaned in trichloroethylene and was then vacuum brushed to insure the obtaining of a grease and particle free surface. The cleaned brake disc segment was immediately placed in a standard electroplating bath as the cathode thereof. The electroplating bath was maintained at a pH value of 4 and a temperature of 130°F. throughout the plating residence time of 15.5 hours at a current density of aproximately 12 amperes per square foot of segment surface area.

Inspection of the nickel plated specimen revealed it possessed a dull coating of approximately 10 mils in thickness.

Subsequent to plating, the segment was accurately weighed and was then placed in the electric furnace of Example I whereupon it was processed at 1600°F. for a period of one hour. The high temperature exposed segment was then removed from the furnace, permitted to cool to room temperature and again accurately weighed whereby the calculated weight loss of the coated segment was determined to be 0.71 percent, a significant reduction due to the presence of the metal coating.

A careful examination of the high temperature exposed coating disclosed the absense of any surface imperfections nor any tendency toward delamination or spalling between the nickel plating and the carbon substrate.

WHAT WE CLAIM IS:—

1. A substantially all-carbon composite annular brake disc, said disc being formed throughout by carbon fibres in a carbonaceous matrix and having protrusions or indentations along one of its peripheries, wherein the region of the disc adjacent said one periphery comprises a band of continuous carbon fibres which are located in said carbonaceous matrix so that they follow substantially the contour of said one periphery of the disc.

2. An annular disc as claimed in claim 1, wherein the periphery is the outer periphery of the disc.

3. An annular disc as claimed in claim 1, wherein the periphery is the inner periphery of the disc.

4. An annular disc as claimed in any of the preceding claims, in which a material having different frictional characteristics than said all-carbon composite is secured to the planar surfaces of the disc.

5. An annular disc as claimed in any one of the preceding claims, wherein said protrusions or indentations along said periphery are in the form of splines.

6. An annular disc as claimed in any one of the preceding claims having, at least in the peripheral region, a surface coating of a material having a melting point greater than 1400°F. or which is a viscous film-forming liquid at 1400°F., the said material being substantially inert in the presence of oxygen and substantially impermeable to the passage of oxygen therethrough.

7. An annular disc as claimed in claim 6 having splines along said periphery thereof, and the surface coating covers at least the splines.

8. An annular disc as claimed in claim 6 or 7 in which the surface coating material comprises a metal, a metalloid or a ceramic.

9. An annular disc as claimed in claim 6 or 7 in which the surface coating is a metallic coating comprising a metal selected from copper, gold, nickel, silver, and combinations thereof.

10. An annular disc as claimed in claim 6 or 7 in which the surface coating is a ceramic material comprising alumina, beryllia, silica, zirconia, boron carbide or molybdenum disilicide.

11. An annular disc as claimed in claim 6 or 7 in which the surface coating comprises silicon or boron.

12. An annular disc as claimed in claims 6, 7 or 8, in which the surface coating includes a plurality of sub-coatings of which at least the sub-coating adjacent to the body has a coefficient of expansion approximately that of the body.

13. An annular disc substantially as described with reference to Figures 2 to 4 or Figures 2 to 4 when modified by Figure 5 of the accompanying drawings.

14. A disc brake assembly comprising a stator disc fixed in relation to an axle and a rotor disc fixed in relation to a wheel mounted on the axle, in which each disc is an annular disc according to Claim 7 and the discs are adapted, by axial displacement, to engage over frictional areas of their adjacent major faces, and in which the surface coating on each disc covers substantially all surfaces of the disc except the frictional area.

15. A disc brake assembly according to Claim 14, in which each disc is a disc according to any of Claims 8 to 13.

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1311537 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

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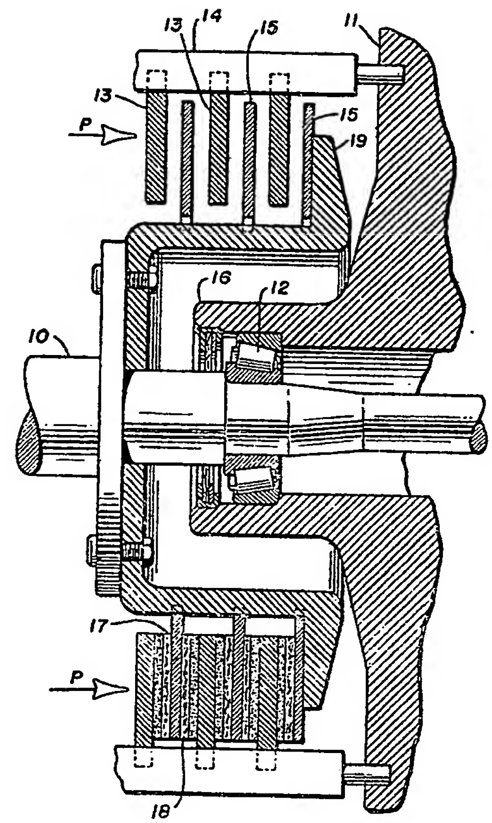

FIG. 1.

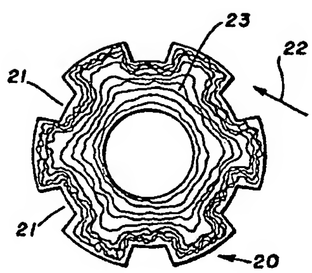

FIG. 2.

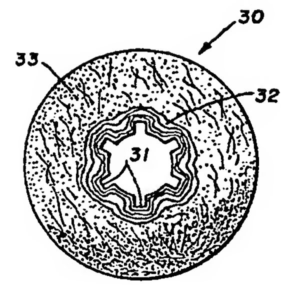

FIG. 4.

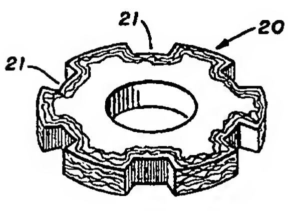

FIG. 3.

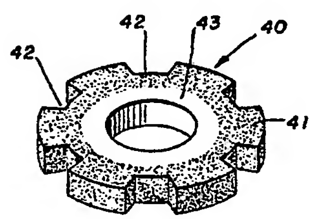

FIG. 5.

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